National Center for Remanufacturing and Resource Recovery (NC3R)

ROCHESTER INSTITUTE OF TECHNOLOGY

Office of Naval Research Grant N00014-05-01-0708

FINAL REPORT

R·I·T Defense Systems Modernization and Sustainment Initiative

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14. ABSTRACT

The National Center for Remanufacturing and Resource Recovery (NC3R) at Rochester Institute of Technology has successfully researched and demonstrated technologies that are able to enhance the performance of defense weapons and support systems, while managing total life-cycle costs. The program areas supported by this ONR grant were Asset Health Management (AHM), Life-cycle Engineering and Economic Decision Systems (LEEDS), Material Aging, and Modernization through Remanufacturing and Conversion (MTRAC). NC3R accomplishments included the development of AHM data analysis and prognostic algorithm development for critical ship and ground vehicle components; AHM system deployment on transportation platforms; LEEDS multimodal maintenance application demonstration; reverse engineering and upgrade for aircraft components; and, platform reliability availability and maintainability assessment.

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2. Executive Summary

The National Center for Remanufacturing and Resource Recovery (NC3R) at Rochester Institute of Technology was awarded the grant entitled Defense Systems Modernization and Sustainment Initiative (N00014-05-1-0708) from the Office of Naval Research (ONR) for the period June 1, 2005 to December 1, 2006. The successful completion of the original award for $3,641,000 (June 1, 2005 to December 1, 2006) led to six modifications totaling $440,000 extending the effort to February 1, 2007 for $4,081,000. This final report is provided in accordance with the grant requirements upon successful completion of the original grant including its extensions.

NC3R's research focuses on developing and demonstrating technologies that enhance the performance of defense weapons and support systems, while helping to monitor and control total ownership costs. NC3R collaborates with a wide range of Department of Defense organizations, such as the Office of Naval Research, Naval Air Systems Command, Marine Corps Systems Command, the Naval Air Depots, Program Manager – Light Armored Vehicle, Marine Corps Combat Development Command, USMC Depot – Albany, GA, USMC Depot – Barstow, CA, and Navy Surface Warfare Laboratory – Carderock Division, in a wide variety of life-cycle engineering projects on several major weapons systems. In support of these diverse customers, NC3R applies remanufacturing and conversion processes, programs to predict equipment health and failure, reliability and maintainability assessment, life cycle technology insertion, rapid reverse-engineering processes, and material analysis technologies to predict the service life of systems and components. These efforts included technology to aid in the design of new military platforms, technologies to support efficient and effective platform operation, and technologies to extend the life of aging platforms.

The efforts conducted by NC3R are organized in terms of 4 different research and development focus areas: Asset Health Management, Life Cycle Engineering and Economic Decision Systems (LEEDS®), Material Aging, and Modernization Through Remanufacturing and Conversion. Results in each focus area are described below.

The Asset Health Management (AHM) program is developing technologies that contribute total asset visibility with a primary focus on platform health. These technologies include embedded diagnostic and prognostic algorithms and software, and hardware for ground vehicle applications. The embedded diagnostic and prognostic technologies also contribute to improved maintenance effectiveness. In addition, the AHM program is developing technologies for analysis and visualization of asset health.

Through these efforts, NC3R has assisted in developing a more robust, cost effective and scalable health monitoring system for ground vehicles. This system has been developed and tested on the Light Armored Vehicle (LAV), and is also being demonstrated on the Medium Tactical Vehicle Replacement (MTVR) and the HMMWV. A commercial

testbed (a Rochester area transit bus) has also been utilized for additional testing of AHM hardware and software. The robustness of the NC3R technology was demonstrated when an LAV with an installed monitoring system sunk during training operations. The monitoring system data was retrieved from the recovered vehicle and provided an analysis of the sinking event.

During the contract period, NC3R also collaborated with the USMC and the Program Manager for the Light Armored Vehicle (PM-LAV) to provide Reliability Centered Maintenance (RCM) training and analysis. RCM is a process for establishing an overall maintenance management plan for all systems of a vehicle with an emphasis on the development of proactive (and condition based) maintenance polices. Through this effort, NC3R provided training to LAV operators and maintainers, conducted a systems level RCM analysis of the LAV in order to prioritize vehicle systems for further RCM study, and, based on that data, selected and completed a detailed analysis of the LAV pneumatic system as the initial RCM assessment. Improved maintenance procedures and opportunities for condition based maintenance were also identified through this process.

LEEDS® (Life Cycle Engineering and Economic Decision System) is a total system approach to optimizing life cycle performance through planned modernization and step-by-step improvements in technological capabilities. LEEDS® was initially developed for the remanufacture of the Surface Effect Ship-200 through a project with ONR. Through various ONR funded projects, the capability of LEEDS® has been extended to provide engineering support throughout the platform life cycle.

There were several major technology development and application initiatives completed or started during this contract period. LEEDS® was originally concepted as a platform life-cycle management tool but new capability needs led engineers to expand the system's software capability to handle fleets of similar platforms. This includes the development of new data visualization tools for analyzing both platform and fleet data.

In addition NC3R undertook a unique new application of LEEDS® through the integration of a multi-modal (combined speech and text) user interface for platform inspections as well as troubleshooting and maintenance instruction. This technology was developed using USMC ground vehicle requirements, and implemented and tested in partnership with the Rochester transit agency on a public bus.

Efforts to apply LEEDS® to a new Alaskan Ice-breaking Fast Ferry, sponsored by the E-Craft program and supported by ONR, have also been kicked off. This effort will extend the decision support capabilities of the software and deploy the system to the borough of Matsu, Alaska, who will operate the ferry for commuters.

Material Aging is the degradation in the physical appearance, dimensions, or physical and mechanical properties of a component during its service life. These changes limit the

useful life of the component and drive many of the critical decisions that face program managers as they seek to extend the useful life of their platforms. Corrosion, wear, stress cracking, as well as catastrophic material or structural failures are all serious manifestations of material aging that must be prevented or repaired.

During the contract period, NC3R's Material Aging research was focused on the development of technologies for imaging surfaces and surface degradation and for repairing these aged surfaces. In addition, military equipment components with diminishing sources of supply were analyzed and repair techniques were developed for several critical components. These projects directly supported the EA-6B Program Office as well as several Naval Air and USMC depots.

Outcomes of the Material Aging research include the development of optical imaging techniques for imaging surface wear and for recovering design data from mechanical components. Also, surface coatings, including metals and plastics, and coating application processes were developed for repairing bearing surfaces.

The Modernization through Remanufacturing and Conversion (MTRAC) assists the Department of Defense in developing the latest technologies and capabilities to respond to ever-evolving defense challenges while also balancing these needs with technology obsolescence issues, product performance, life-cycle costs, and time constraints. Once investments in systems have been made, other decisions come up throughout that product's life such as when to upgrade, convert, repair, replace or remanufacture components to protect the investment and keep equipment operating better and longer.

Under this contract, NC3R continued to do research and develop technologies that support modernization of the current fleet of military equipment. In particular, NC3R analyzed technology upgrade options for the Light Armored Vehicle, developed a prototype auxiliary power supply for the LAV turret, and reverse engineered and developed a technical data package for an out-of-supply LAV communications circuit board. NC3R also supported analysis of additional sustainment problems of the LAV as identified by engineering support work directives under the Product Data Management Initiative (PDMI) by the Defense Logistics Agency (DLA).

An additional effort was undertaken to develop and apply life-cycle design technologies to the Unmanned Sea Surface Vehicle for the US Navy. A new life cycle engineering process (Innovation Based Design – IBD) was developed to optimize life cycle functionality, reliability, and life cycle cost. This process develops technology roadmaps and reliability and cost models that allow a new concept to be optimized during the design phase, taking into account the impacts of changing requirements during the life-cycle, maintenance and support, recapitalization, and waste disposal impacts. In conjunction with Carderock labs, the IBD analysis was demonstrated for two unmanned sea surface vehicle concepts, providing design recommendations for the two concept platforms.

NC3R continues to organize their research efforts using the proven approach of identifying military platforms and stake-holders with specific technology needs that line up with our research roadmaps. This approach provides the dual benefits of a source of research direction and requirements from military equipment operators, maintainers, and life-cycle managers as well as a natural transition path for their research.

3. Introduction to the National Center for Remanufacturing and Resource Recovery at Rochester Institute of Technology

Founded in 1997, The National Center for Remanufacturing and Resource Recovery (NC3R) at Rochester Institute of Technology was the nation's first academic research facility devoted to the study of remanufacturuing.

CIMS building on the RIT campus

Today, NC3R is an international leader in remanufacturing and industrial reuse, sustainable design and pollution prevention. NC3R is a dynamic collaboration of over 40 dedicated engineers and technicians supported by RIT faculty and students. The center is currently housed in the Center for Integrated Manufacturing Studies (CIMS) on the RIT campus and takes advantage of the facility's 170,000 square feet of laboratory and office space, six research bays and 10 room, 400 seat conference and training center, equipped with smart capabilities.

Through its partnership with industry, the center has assisted numerous manufacturers in improving efficiency and enhancing environmental quality. Since 1998, NC3R has completed 640 technical assistance projects helping to create 683 new jobs, retain 795 more, reduce expenses by $8 million, and increase sales by $96 million.

In addition, NC3R has developed a unique partnership with the United States Military to enhance remanufacturing and reuse, reduce costs and ensure the safety of our troops in the field. For example, research conducted on the US Marine Corps' Light Armored Vehicle has extended the life of the existing fleet by 20 to 25 years, saving the military approximately $42 million.

The center was founded and continues to be led by Dr. Nabil Nasr, an international expert in sustainable design and environemntally conscious manufacturing who has spent over two decades assisting companies and government agencies in enhancing profitability while also reducing environmental impact. Dr. Nasr currently serves on the National Research Council's Board on Manufacturing and Engineering Design and the National Science Foundation's Environmentally Benign Manufacturing Team. He is also chair of the Remanufacturing Industries Council.

One of several research bays

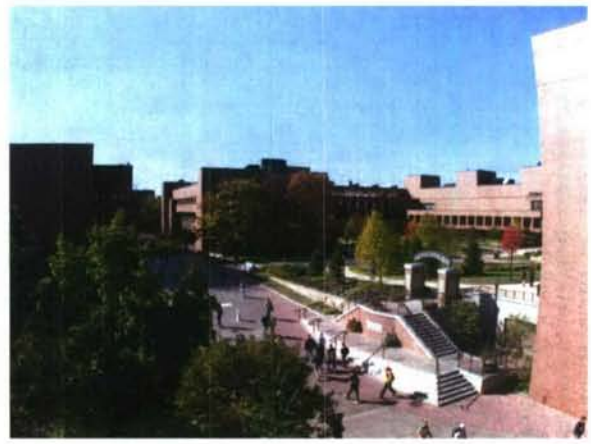
In response to the signicant impact the center's research has achieved, Dr. Nasr and NC3R has received several national honors, including the National Center for Advanced Technologies' 2004 Defense Manufacturing Excellence Award and the National Pollution Prevention Roundtable's 2006 MVP^2 award.

Rochester Institute of Technology (RIT)

Founded in 1829, RIT is an internationally recognized leader in professional and career-oriented education enrolling more than 15,000 students. RIT has one of the oldest and largest co-op programs in the world. RIT is coeducational and the 11th largest private university in the nation.

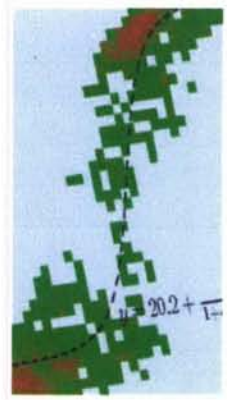
RIT offers 350 programs of study in eight colleges including the Kate Gleason College of Engineering, the E. Philip Saunders College of Business, and the B. Thomas Golisano College of Computing and Information Sciences. The university is internationally respected for its research and educational programs in imaging and color science, photography and remanufacturing as well as its work in experiential learning and cooperative education.

RIT's modern 1,300-acre campus is located in Rochester, the third largest city in NewYork State.



RIT campus

Asset Health Management



4. Asset Health Management

4.1. Description of Asset Health Management

Asset Health Management (AHM) is a set of technology driven processes that support the optimization of weapons system readiness and supportability. The AHM system ties together technology enabled weapon systems and technology enabled maintainers, both with connectivity to critical support systems. In addition, AHM also supports the information needs of battlefield commanders and logisticians.

AHM technology development efforts to date have been focused on technology that supports improved readiness and maintainability of current military platforms. Many current platforms are having their life cycles extended past the original design intent. An investment in AHM technology can aid in achieving readiness goals while managing supportability costs. These technology investments can also prepare current platforms to meet the evolving requirements for advanced decision support systems for battlefield Logistics and Command and Control (Autonomic Logistics). Figure 1 below outlines a series of AHM technologies and applications utilized by the NC3R team.

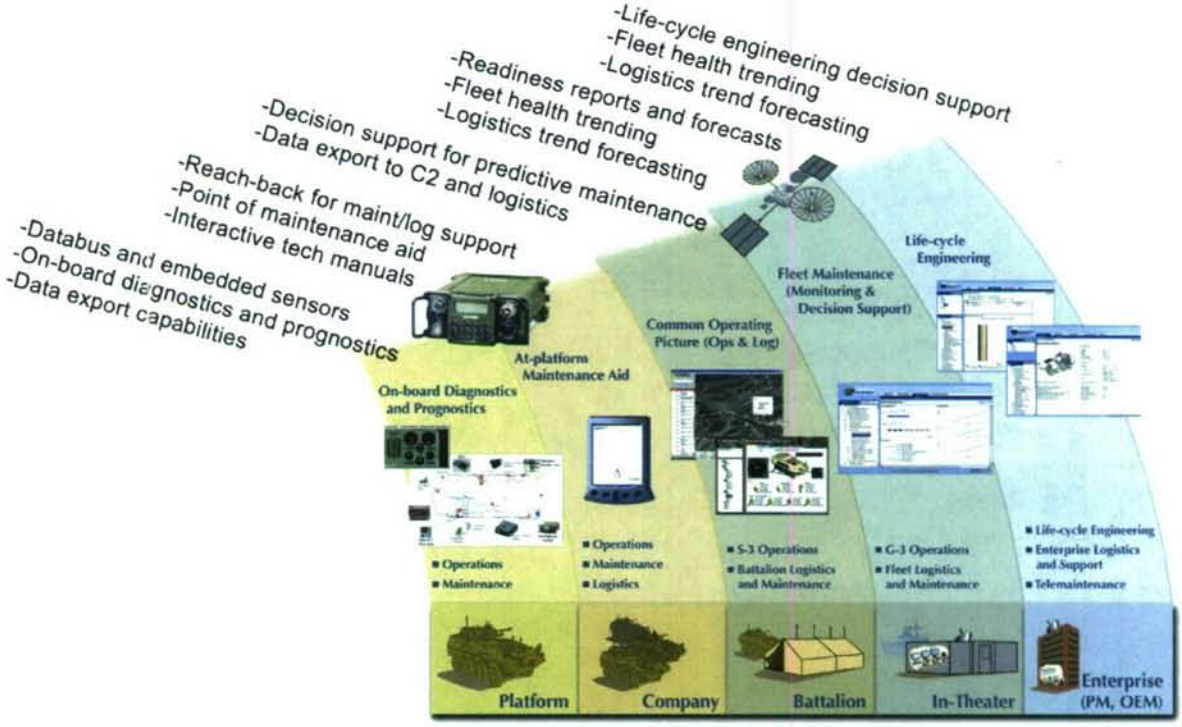


Figure 1. AHM Technologies and Applications

Table 1 below illustrates AHM program developments during the contract period. The research conducted is a natural extension of the technology applications from previous ONR supported efforts. This work focused on additional vehicle applications (and deployment) of our AHM technologies, development of more generic and robust hardware and software components for our AHM system, an extension to our off-board data analysis capability at the platform and fleet level, and more in-depth work in the area of prognostics for mechanical and electronic components.

Table 1. Asset Health Management Program Activities

Previous Development	Current Development	Future Development
On-board Diagnostics and Prognostics Hardware and Software	Reliability Centered Maintenance Process with Integration of Monitoring Technologies	USMC Technology Transition
Off-board Monitoring and Fleet Trending	Platform and Fleet Maintenance Decision Support Tools	Integrated Development /Deployment Software for Diagnostics and Prognostics
Development and Documentation of Monitoring Deployment Process	Electronics Reliability & Aging	Electronics Diagnostics/Prognostics

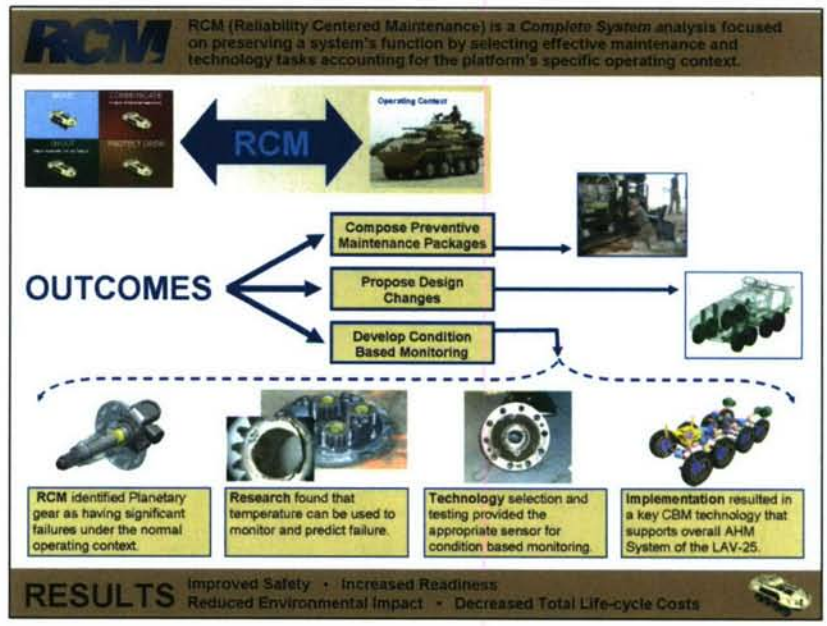
4.2 Asset Health Management Research Objectives, Progress, and Results

A primary objective of the Asset Health Management research is to assess cost benefit of the deployment of health monitoring technologies to U.S. Marine Corps ground vehicles. Several different research initiatives supported this end goal: Reliability Centered Maintenance (RCM) application to the Light Armored Vehicle (LAV), improvement of the scalability and cost effectiveness of the NC3R on-board hardware and software health monitoring architecture, application of that architecture to other vehicle platforms, and prototyping and refinement of systems and algorithms for off-board data analysis of vehicles and fleets.

The U.S. Marine Corps has mandated the use of Reliability Centered Maintenance for optimization of maintenance costs and effectiveness, however RCM best practices have not been defined. The Light Armored Vehicle Program Managers Office (PM-LAV) has been interested in using RCM as a mechanism to identify opportunities for Condition Based Maintenance (CBM) and health monitoring, and the resulting sensing requirements. NC3R's research initiative is applying RCM to the LAV at the system level and has already completed analysis of one critical vehicle system in order to develop an effective methodology for RCM analysis. Opportunities for improvements to current maintenance procedures were identified in addition to sensor based CBM opportunities.

Follow-up research opportunities include the use of the RCM knowledge base to drive diagnostic and troubleshooting procedures.

During the contract period, significant progress was also made on the development of a more robust and cost effective architecture for on-vehicle health monitoring. Generic sensor interface modules (J1939 compliant) have been prototyped, an interface to the SAE J1708 diagnostic databus was developed and deployed, and an integrated power supply that meets commercial and military specifications for electrical system voltage transients was developed. The updated hardware and software architecture has been deployed to a Rochester city transit bus, through a project with the Rochester Genesee Regional Transportation Authority, in support of a demonstration of voice based inspection and maintenance technologies, and to get field verification experience prior to deployment on LAVs at Camp Pendleton. In addition, initial investigations into application of the updated health monitoring system to the USMC Medium Tactical Vehicle Replacement (MTVR) indicate the flexibility of the next generation system. Next steps include refinement of new hardware components (and associated software), deployment of the updated system on one or more LAVs at Camp Pendleton, and a multi-vehicle demonstration of the flexibility of the system utilizing an LAV, HMMWV, and MTVR.



LAV RCM analysis

Several AHM initiatives have also been focused on improved analysis of vehicle data off the platform. A significant amount of operational information was generated from the deployment of the first NC3R health monitoring system on an LAV at Camp Pendleton. This vehicle is no longer in service as it was sunk during amphibious testing, however the data in the on-board monitoring system was recovered and analyzed.

As a part of PM-LAV's continued investigations into vehicle health monitoring, the National Center for Manufacturing Sciences (NCMS) has funded a broader deployment of health monitoring systems to ten LAVs. In support of this initiative, NC3R has updated our Common Operational Picture (COP) in order to give the Marines a means to analyze the operational data from monitored vehicles. The deployment of these technologies to Camp Pendleton is currently underway and data from this broader group of vehicles will be available for analysis in the near future.. We have also begun to conceptualize approaches for off-board analysis of individual vehicle data (and also fleet data). These data visualization and analysis methods are being integrated into the NC3R Life-cycle Engineering and Economic Decision System (LEEDS®)

testing AHM equipment at Camp Pendleton

Finally, NC3R has worked throughout the contract period to improve their research capabilities in the field off prognostics, the assessment of remaining life or prediction of future failures. Prognostics can provide substantial benefits to improved operational reliability and provide the basis for proactive or predictive maintenance. While there is a significant amount of literature and conference papers related to prognostics, real applications remain limited and there is a need for continued research. NC3R has worked to close this application gap through continued research into prognostics for planetary gears of the LAVLAV planetary gear prognostics as well as prognostics for a variety of electronic components. The LAV planetary gear algorithms utilize system temperature as a measure of the health of the system. Failures of the weak link in the planetary can be prognosticated by predicting the future state of the system. Damaging operational states can be predicted, as well as abnormal states caused by component degradation. The general methodology developed for the planetary can be applied to other systems, but is application specific. The work in electronics is focused on a better understanding of the system stressors that accelerate failures, and component and system level indicators of degradation leading to failure. This work is still in the preliminary stages.

4.3. Asset Health Management Projects

As shown in Figure 4.2, the primary projects that were conducted under the Asset Health Management program include:

Ongoing Projects

- Asset Health Management Hardware and Software (2nd Generation)
  - J1939 Data Acquisition
  - J1939 STE-ICE Module
  - System Health Node (and UPS)
  - MIL-1275 Compliant Vehicle Power Supply
- Fleet Data Visualization and Decision Support
  - AHM/LEEDS Integration
- Asset Health Management System Deployment
  - AHM Deployment/Validation: Rochester Genesee Regional Transportation Authority (RGRTA)
  - Hardware and software upgrades and deployment: USMC LAV Gen II
  - Demonstration Systems:
    - USMC Medium Tactical Vehicle Replacement (MTVR)
    - HMMWV
- Platform and Fleet Data Analysis Methods
- Electronics Reliability and Prognostics
  - HALT/HASS Test Methodology Development
- Wireless Planetary and Differential Sensors
- National Center for Manufacturing Sciences (NCMS II): LAV Life Cycle Monitoring Support
  - Common Operating Picture
  - Data Analysis Support

Completed Projects

- Reliability Centered Maintenance (RCM) of LAV 25 (June 06)
  - RCM Analysis Software Tool
  - Platform Level LAV-25 Analysis
  - RCM Analysis of the Pneumatic System
- LAV Data Analysis and Planetary Prognostic Algorithm Development (June 06)
- After Action Data Analysis from Sunk LAV (June 06)
- Common Operational Picture Upgrade (June 06)

Asset Health Management

PROJECTS

Asset Health Management

Ongoing Projects

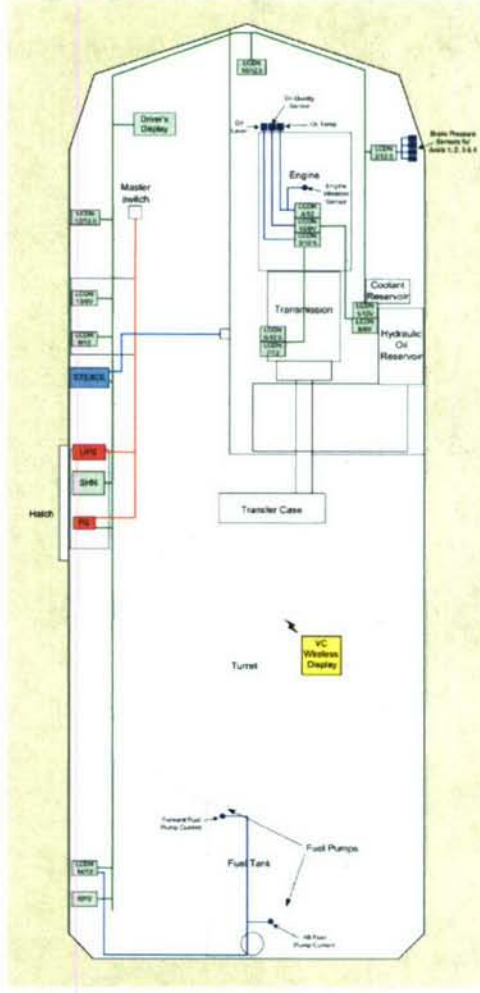
1. Asset Health Management Hardware and Software (2nd Gen)

Sub-Task: 1.2

Project Goal

Develop hardware for a second generation Asset Health Management (AHM) system. Evaluate the field performance of first generation (AHM) hardware based on the feedback from the LAV fielding at Camp Pendleton, California. Design and build 2nd generation hardware components that facilitate a scalable and manufacturable system for application to a larger number of military vehicles.

NC3R deployed its AHM Gen I system and software on an LAV 25 at Camp Pendleton, California in December of 2004. This has allowed the center to field test its hardware for an extended period of time under varying loads and conditions. Feedback from the Marine Corps during this period has been very favorable and has generated the need for a follow-on system that can be manufactured and built for a larger number and differing types of vehicles. Hardware is being designed and built that will not only extend the capability of the AHM system but is modular in nature so that a system can be readily tailored both in collection complexity and cost. Hardware decisions are also being made considering the ease of manufacturing, ability to meet military standards, and robustness of the system.



NC3R's 2nd Generation Asset Health Monitoring System for the LAV

Project Results to date

- Prototypes of all system components have been completed and the system has been installed in a retired LAV AD vehicle located at RIT for testing. It is anticipated that the system will be deployed to Camp Pendleton for field testing late in 2006.
- A broad range of new sensors has been added, including oil quality and oil level sensors for the engine and transmission. Pre-existing sensors and signals are used wherever possible.

- NC3R has designed a data acquisition component that can directly read the collected signals from the Standard Test Equipment for Internal Combustion Engine (STE-ICE) and transmit the data over a J1939 databus. This will allow the AHM system to be quickly applied to a number of legacy platforms equipped with STE-ICE capability.
- NC3R has designed a generic Data Acquisition (DAQ) Node that is capable of interfacing to a wide range of sensors and transmitting the data over a J1939 databus. The component is designed to be low cost so that it provides the flexibility for a scalable AHM system design – tailored to the needs and budget for a particular platform.
- NC3R did an extensive survey and benchmarking of Uninterruptible Power Supply technology for possible application to an AHM system. The first design concept has been completed for a UPS board to support the next generation AHM system for the LAV.
- NC3R completed the first design concept and preliminary drawings for a power supply to provide clean power and protect the AHM system from various electrical system anomalies in accordance with applicable military specifications.
- NC3R a first prototype of a low cost Global Positioning System (GPS) node that can provide location data over a J1939 databus.

2. Fleet Data Visualization and Decision Support

Sub-Task: 1.4

Project Goal

Integrate the capabilities of the NC3R Asset Health Management (AHM) program and the Life-cycle Engineering & Economic Decision System (LEEDS®) in order to use the AHM generated historical data for making platform based assessments, a foundation for making overall fleet level management decisions.

NC3R's AHM program to date has focused on the monitoring of individual assets using data collected from a network of sensors that is then processed by a main system health node that interprets this information into a series of meaningful alerts and events. This data can be used to assess the overall health of the individual vehicle. LEEDS® software is a database and decision support system for long-term systems management of large, complex platforms, allowing for performance and cost alternatives to be clearly mapped when making life-cycle decisions about maintenance, remanufacturing, operating costs, and modernization efforts. During this contract period, NC3R began the effort to merge the capabilities of these two programs in order to take platform level maintenance histories, usage statistics, trend analysis, and system health captured by the AHM program and port to LEEDS® to make better informed decisions as part of a Total Systems Life Cycle Management (TLCSM) process.

Project Results to date

- Developed a technology survey and benchmarking of software to be used as an interface between AHM and LEEDS®.
- Developed the first set of algorithms for trending alerts and discriminating between system or signal causes.
- Developed a prototype portal within LEEDS® to display AHM data, with the ability to drill down into lower level alerts.

3. Asset Health Management System Deployment

Sub-Task: 1.3

Project Goal

Evaluate the capabilities of the NC3R AHM technologies in different vehicle applications. This will provide other drivers of system requirements, and additional platforms for testing and verification of the technologies.

To date, NC3R has deployed our AHM technology to USMC HMMWV and LAV vehicles. Both of these vehicles are relatively old technology and do not have existing modern digital diagnostic data buses. This task will investigate the deployment of AHM technologies to a Rochester city transit bus, and to the USMC MTVR vehicles (Medium Tactical Vehicle Replacement – a heavy truck). The transit bus will provide a local application with a very high usage for technology verification purposes. The MTVR will provide a DoD example of the extensibility of the AHM system to multiple platforms.

Project Results to date

- Developed an interface to the SAE J1708 diagnostic databus.
- Deployed the NC3R system health node (and software) on a transit bus at RGRTA. The mobile system is wirelessly integrated into a web-accessible database and NC3R backend data analysis tools.
- Have investigated application of the NC3R AHM technologies to the MTVR. The MTVR utilizes an SAEJ1708 databus which provides similar data to the RGRTA transit bus. This application will be utilized for the USMC 2006 SAE Defense Maintenance Symposium Sense and Response demonstration.

technology demonstration at RGRTA in Rochester, NY

4. Platform and Fleet Data Analysis Methods

Sub-Task: 1.4

Project Goal

Develop methods for analysis of health assessment data from individual vehicles and vehicle groups

This project will extend health assessment algorithms previously developed, including assessment of vehicle fleets, and individual vehicles in fleet context. PM-LAV is deploying monitoring systems on ten Light Armored Vehicles at Camp Pendleton California, these vehicles will be used as a living test bed for this project.

Project Results to date

- Preliminary data analysis methods have been concepted, along with reports for maintainers, operators, and commanders based upon data from previous LAV monitoring
- Additional analysis is awaiting data from the fleet of LAVs

5. Electronics Reliability and Electronics Prognostics

Sub-Task: 1.6

Project Goal

Develop a Highly Accelerated Life Testing/Stress Screening (HALT/HASS) laboratory and methodologies for accelerated testing of electronics failure and reliability as a precursor to the development of prognostics for electronic components.

NC3R is in the process of developing the capability to do accelerated testing of electronic systems to identify and characterize design and manufacturing characteristics that affect reliability, durability and overall robustness. This capability will support future research in health monitoring technologies that predict impending failure and/or remaining life of electronic systems. A component of the LAV AHM system is being used as a test case for technology development.

HALT/HASS testing

Project Results to date

- NC3R has acquired, installed, and debugged an Allegan OVS-3 Environmental Test Chamber for HALT/HASS testing.

- NC3R conducted an RCM analysis of an AHM power supply component in order to identify opportunities for condition monitoring.
- Preliminary testing vibrational and thermal testing of a DC/DC power supply has been conducted.

6. Wireless Planetary and Differential Sensors

Sub-Task: 1.2

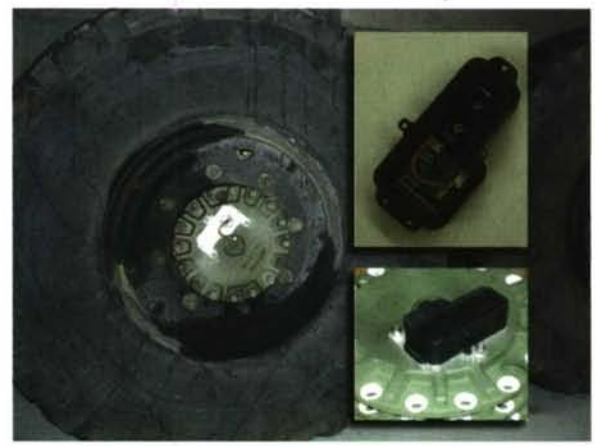
Project Goal

Design a small wireless device that is modular in design with a "plug in" sensor that can support the most common remote sensor requirements for condition based monitoring of military platforms.

NC3R's experience in applying AHM to different military ground vehicles has generated a need for data that can only be acquired by sensing the state of various parts, lubricants, and sub-systems that are difficult or impossible to sense with wired components. In particular, the LAV has critical drive train components that cannot be monitored with wired sensors. The requirement for a versatile wireless monitoring device that can interface to a vehicle databus and also meet the environmental requirements of a military is not being currently met by the commercial marketplace. In order to provide accessibility to critical signals that are needed to develop health assessment methodologies, NC3R is developing a prototype wireless sensing system that will interface with a J1939 databus. This system should be ready for the Gen II system deployment in the fall of 2006.

Project Results to date

- Battery powered IEEE 802.15.4 wireless node was developed for wireless temperature measurement
- Controller was developed for interfacing with 802.15.4 sensor nodes and reporting sensor data on SAE J1939 databus
- Development and refinement of this hardware continues, including mechanical packaging and extended battery life



NC3R Designed Wireless Temperature Sensors for LAV

7. National Center for Manufacturing Sciences (NCMS): LAV Life Cycle Monitoring Support

Sub-Task: 1.1

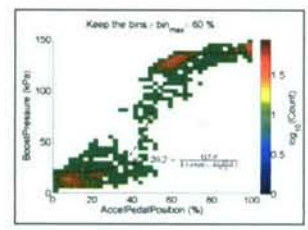
Project Goal

Provide a COP for use by the Marine Corps School of Infantry and analyze the Asset Health Monitoring data collected from the fleet of ten (10) vehicles that was installed by a NCMS collaboration of industrial and military partners.

NC3R teamed with the National Center for Manufacturing Sciences (NCMS), the Program Management Office for the Light Armored Vehicle (PMLAV), the Naval Weapons Station Crane Joint Distant Support and Response (JDSR) team, and a number of industrial partners in an effort to install an AHM monitoring system on a fleet of vehicles at the School of Infantry at Camp Pendleton, California. As part of the effort, NC3R was asked to provide a COP to visually demonstrate the capability provided by a fleet of vehicles that had an onboard AHM system to all the stakeholders. The newer version of the COP was demonstrated at the 2005 Defense Maintenance Symposium. Finally, as the data is amassed by the onboard systems, NC3R will analyze the information to look for ways that it can be exploited by PM-LAV in the areas of autonomic logistics, condition based maintenance, material aging, diagnostics, and prognostics. This data analysis effort is scheduled to begin in October of 2006.

Project Results to date

- RIT has developed a database transformer that can:
  - Quickly extract the information necessary to run the COP from the overall sensor database.
  - Run as a periodic service that can recognize when a vehicle has been updated and begin the extraction.
- Extended the capability of the COP to allow for:
  - Playback of pre-recorded mission data directly from the database.
  - Improved and simplified user interface that allows for tabbed sections for operations, maintenance and logistics, better graphics, and more intuitive information retrieval.



feature extraction for trend analysis and anomaly detection

- Began the development of a software algorithm to do anomaly detection, trending, and future state prediction for the LAV planetaries.
- Coordinated with JDSR to develop the procedures, including the required security measures, for transferring the data rapidly back from the vehicles in California to NC3R.

Completed Projects

1. Reliability Centered Maintenance (RCM) of LAV-25 Pneumatic System

December 2005 thru June 2006

Sub-Task: 1.5

Project Goal

Refine the NC3R RCM software analysis tool and use it to conduct an initial RCM analysis of the LAV-25 overall system and extensive RCM analysis of it's Pneumatic System in order to develop a maintenance program, reduce operating costs, investigate CBM technology opportunities, and make recommendations for current and next generation vehicle design modifications.

NC3R designed a RCM software tool to facilitate the collection and presentation of data during an RCM analysis. The prototype software was used during an overall RCM analysis of the LAV-25, conducted with PMLAV and engineers from the Depot in Albany GA. The purpose of the initial study was to identify critical systems of the LAV-25 hull that were candidates for a detailed RCM analysis. The NC3R software was then refined based on feedback from this analysis and used for the follow-on study. Building upon the results of the overall LAV-25 RCM investigation, NC3R teamed with PMLAV and active duty United States Marines from 2nd LAR Battalion and the Marine Detachment from Aberdeen Proving Grounds to conduct a detailed RCM analysis of the LAV-25 pneumatic system, which had been identified by the RCM analysis team as the most critical subsystem for the hull. NC3R first conducted a detailed investigation of the pneumatic system to include a functional breakdown, operational context and hardware partitions in preparation for the analysis. A three week RCM analysis was then facilitated by RIT, using the NC3R RCM software tool, with a team of PMLAV engineers, Marine Corps operators and maintainers to capture failure modes effects analysis (FMEA), develop work breakdown tables, modify maintenance tasks and recommend design changes. A final report and presentation based on the results was prepared and delivered to PMLAV for action.

RCM training

Project Results

- Developed, prototyped, refined and completed an NC3R RCM software analysis tool.
- Provided a rank-order list of subsystems of the LAV-25 hull as to their criticality and suitability for RCM analysis.
- Developed and delivered a customer specific RCM workbook and class for the training of ten students

from 2nd LAR Battalion, Marine Corps Depot Albany, Aberdeen Proving Ground, and PMLAV.
- Completed the detailed RCM analysis of the LAV-25, Pneumatic System and provided a final report that included specific recommendations to PMLAV for changes to maintenance manuals, maintenance procedures, repair parts changes, condition based monitoring opportunities, and design changes.

2. LAV Data Analysis and Planetary Prognostic Algorithm Development

Sub-Task: 1.4

Project Goal

Collect data from an onboard Asset Health Monitoring System that is performing in an operational environment and use this information for prognostic algorithm development.

NC3R installed an Asset Health Monitoring system on board a Light Armored Vehicle at the School of Infantry in Camp Pendleton, California that was used for crewmen and leader training. The onboard system is currently collecting data during an assortment of missions including on-road, off-road, and swimming. NC3R was given unlimited access to the vehicle, data, and operators in order to gather information about the performance of the system, and based on this suggested changes that will be incorporated into the follow on system. Data collected was also used for the development of more robust planetary algorithms and trending/fleet monitoring efforts.

Project Results to date

- A temperature based algorithm has been developed to identify statistically significantly deviations in planetary gear operating condition.
- A temperature based (state projection) algorithm has been developed that can provide 10 minutes warning of planetary failure, or of operating states that can cause significant damage to the planetary.
- NC3R has used the collected data for trend analysis and begun development of planetary prognostics algorithms.

3. After Action Data Analysis from Sunk LAV-25

March 2006 thru June 2006

Sub-Task: 1.1

Project Goal

Conduct a detailed analysis of data recovered from the NC3R Asset Health Monitoring (AHM) System after a catastrophic sinking of monitored LAV-25.

NC3R teamed with PMLAV and active duty United States Marines from Light Armored Vehicle Company (LAV CO) School of Infantry (SOI) to conduct a field test of an AHM system on an LAV-25 from December 2004 through March of 2006 at Camp Pendleton, CA. On 23 March 2006, while conducting driver water operations training, the AHM monitored LAV-25 (S/N 521583) sank in 20 feet of saltwater due to operator error and it remained submerged for a period of about five hours. Once the vehicle was recovered by the Marine Corps, RIT deployed a team to Camp Pendleton to retrieve the onboard system. A detailed analysis of the effects of the sinking on the equipment and an analysis of the recovered data was conducted at NC3R's laboratories at and a report was provided to the Marine Corps through PMLAV and SOI CO. A number of design changes for the follow-on system were based on the damage that was observed due to the vehicle sinking.

Project Results

- Despite some limited water intrusion into the AHM System Health node NC3R was able to recover the data collected prior to and during the actually vehicle sinking.
- NC3R provided a detailed report to the Marine Corps that gave a meticulous, second-by-second analysis of the vehicle sinking that was used for the incident investigation and the follow-up, after action training safety review.
- Examination of the water damaged equipment and follow on design review provided valuable data that was incorporated into a series of mechanical changes for the second generation AHM system.

recovered system health node

4. Common Operational Picture Upgrade

November 2005 thru June 2006

Sub-Task: 1.1

Project Goal

To improve the NC3R Common Operational Picture (COP) based upon feedback from Marine Corps Commanders, Operators and Maintainers.

NC3R teamed with PMLAV, Headquarters Marine Corps Installation & Logistics (HQMC I&L) and active duty United States Marines from Light Armored Vehicle Company (LAV CO) School of Infantry (SOI) to conduct user testing on NC3R's COP in order to develop a more richer set of requirements and improve its utility. A Statement of Requirements was developed based on user feedback and a number of revisions were made to meet these new demands. A new scheme for the display of positional data and

status information was implemented with integration of the commercial Google ™ Earth mapping product. In addition, new software utilities were introduced to minimize post backs to the supporting server. All these innovations allowed for the deployment of COP onto the internet and enabled users from outside the NC3R facility to access collected data. This access will be critical in providing feedback to NC3R researchers from a larger set of users.

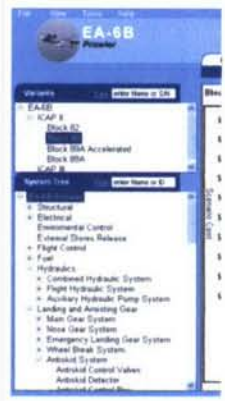
COP interface

Project Results

- Full integration of the NC3R's COP with the commercial tool Google™ Earth.
- Deployment of COP to the World Wide Web for use by selected users across the Marine Corps (http://ses200.cims.rit.edu/COP3/)

LEEDS®

Life Cycle Engineering and Economic Decision System



5. Life Cycle Engineering & Economic Decision System (LEEDS®)

5.1. Description of Life Cycle Engineering & Economic Decision System (LEEDS®)

The Life Cycle Engineering and Economic Decision System (LEEDS®) is a computer assisted decision support tool that optimizes life cycle system performance through planned modernization and step improvements in technological capabilities. The system is designed to improve an owner's decisions relating to life cycle costs and technology refreshment for systems during operating life and at end-of-life. The benefits gained by utilizing LEEDS® to determine optimal system remanufacturing options is augmented by the ability to provide systems operators a portal to maintenance manuals, drawings and other references, as well as the ability to indicate when proactive measures should occur in order to minimize life cycle costs and maximize performance.

A LEEDS® implementation on a vessel.

Table 5.1 links past, present, and future efforts of development activities. LEEDS® has been applied to naval vessels through collaboration with the Office of Naval Research, Lockheed-Martin, and Navatek Ltd., and to ground vehicles through collaboration with the United States Marine Corps.

Table 5.1. LEEDS® Program Activity

Previous Development	Current Initiatives	Future Development
AHM Diagnostic and Prognostic systems	Platform Performance Monitoring	Fleet Performance Monitoring Portal
Remanufacturability Decision Support	Fleet Recapitalization Decision Support	Life Cycle Support from Design
Maintenance Support	Intelligent Maintenance Software Tools	
	Data Collection from Design	

The activities for the contract period were designed to build upon previous technology development efforts of both LEEDS® and the Asset Health Management (AHM) program. Platform Performance Monitoring was achieved with the integration of data produced by AHM Diagnostic and Prognostic systems into the LEEDS® framework, providing usage, anomaly and performance data to platform owners. Recapitalization tools were enhanced with the addition of fleet configuration management and value analysis capabilities. Intelligent maintenance functionality was accomplished by expanding existing LEEDS® maintenance support capabilities with the successful development and demonstration of multimodal interactive maintenance applications and investigative studies into the applications of case-based reasoning and handheld devices with LEEDS®.

Technology Gaps and Research Objectives

Ideally, Program Managers would be able to make informed decisions regarding enhancements to major fielded systems and design new systems in a way that provides maximum readiness at minimum cost while reducing acquisition cycle times. Processes must exist to aid in the tough trade-off decisions that balance risk, product performance, cost, and cycle time considerations, not just for one system but for an entire fleet. Due to the complexity of the analysis, such processes can benefit from computer assisted decision support technologies such as the tools NC3R developed during this contract period.

In order to optimize modernization decisions, NC3R believes such processes should be integrated with system operations throughout the life cycle. This will not only allow the capture and storage of data critical to the decision process, but will also aid in the timing and implementation of remanufacturing/technology insertion cycles to minimize life cycle costs.

Life Cycle Engineering and Economic Decision System (LEEDS®) is both an engineering process and a software tool that was refined by NC3R during this contract period to address this need. LEEDS® assists with decisions about the modernization, remanufacture, maintenance, and operation of large, complex systems.

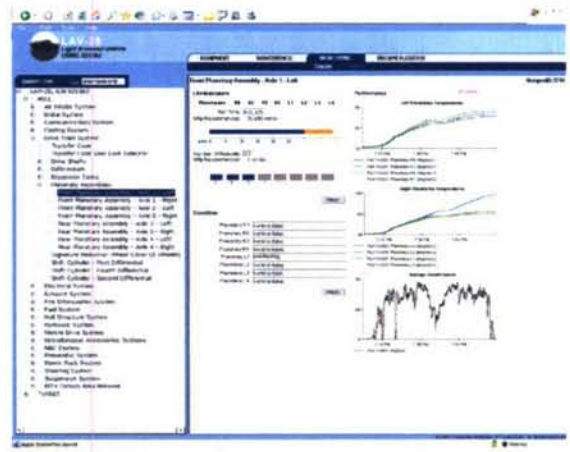
LEEDS® was divided into four major initiatives based on where it is implemented within a system life cycle and the number of platforms in the fleet:

- LEEDS®-R is the application of the process during remanufacturing, at system end-of-service. It encompasses an efficient technical and economic feasibility assessment process. This has been successfully piloted during this contract period and will provide the foundation for the continued development of the LEEDS® process and software tool.

- LEEDS®-D refers to the application of the process that commences during system design and continues to end-of-life. It allows global optimization of life cycle costs through periodic remanufacturing/technology insertion feasibility assessment processes.

- Fleet LEEDS® focuses on helping Program Managers to maintain the readiness of their assets by assessing equipment recapitalization options. It provides tools to aggregate equipment data and to analyze the impact of investment scenarios across the fleet.

- LEEDS®-AHM is the newest NC3R effort to enhance intrinsic recapitalization decision tools by leveraging the vast monitoring data generated by the AHM diagnostic and prognostic systems over the life of a



LEEDS®-AHM

platform. Although the direct benefit of AHM is to aide in maintenance troubleshooting and to forewarn of impending failures, all of the underlying system data may be used to make more informed recapitalization decisions. The first step of leveraging the AHM data that was covered in this contract period was to develop a portal to the platform's anomaly, usage, and performance data to be viewed within the LEEDS® framework.

The evolution of LEEDS® has focused on improving an owner/operator's decisions relating to equipment life cycle costs throughout system operating life, not only at end-of-life. LEEDS®-D was created to provide data collection from design capabilities to serve as an efficient method for the identification, collection, and storage of pertinent system specifications from initial design and construction activities. These specifications in addition to the wealth of data that accumulates during system life cycles, is warehoused in a centralized repository and will allow LEEDS®-D to serve as an on-board maintenance support tool as well as a performance monitor of key systems. The E-Craft/Alaskan Fast Ferry project has been chosen as the application to further develop such capabilities within LEEDS®-D. The novel structure of E-Craft, currently under design, will provide ample opportunities for condition monitoring and unique maintenance procedures.

LEEDS® can be applied to a variety of platforms

In addition, the platform performance monitoring capability made possible by AHM- LEEDS® integration will allow program managers and engineers to remotely view monitored system anomalies, usage and performance. Such data can be used to identify trends and better understand the overall condition of fielded platforms. Ultimately, it is the intention to automatically merge available condition and performance data with other design data when making maintenance and recapitalization decisions.

Investigation of intelligent maintenance software tools was also conducted during the contract period to examine various technologies that could be employed to make use of the vast design, condition, and recapitalization data store contained within LEEDS®. Investigations into the use of case-based reasoning (a form of computer-enabled knowledge management) and porting the LEEDS® software to handheld devices was conducted to identify efficient methods for maintainers to access system data. This investigation was continued with the development of several multimodal (voice-enabled) maintenance tools. These tools, designed for maintenance inspection, troubleshooting and repair applications, were successfully demonstrated for the project sponsors and illustrated the capability of maintenance aids to efficiently and accurately access and record volumes of information, using present-day voice technology.

Finally NC3R worked to develop fleet recapitalization decision support by combining fleet configuration management capabilities with value analysis tools. The development of these capabilities utilized data from the US Navy EA-6B fleet. Tools were developed that leveraged the configuration, condition and economic data to compare competing recapitalization options to meet the goals of lower operating costs, higher reliability and enhanced performance. With LEEDS® Fleet, the Department of Defense can easily review and analyze maintenance, modernization, and remanufacturing decisions.

Future development of the LEEDS® toolset will follow the natural growth of the system to further augment performance monitoring capabilities by viewing not only the data for one platform, but by comparing the data from platforms across the entire fleet, regardless of operational theater. The prognostic packages under development in the Asset Health Management program will assist this effort by reducing time consuming data collection needed when conducting condition assessments of pieces of equipment. In addition, future development of LEEDS® will integrate decision support tools that improve trouble shooting efficiency.

The aim of research during this contract has been designed to build upon previous technology development efforts of both LEEDS® and the AHM program. Based upon the projects chosen and successfully completed during this period, significant progress has been made toward the integration of these two programs, which will result in the development of a more cohesive life cycle support program.

In addition, through NC3R's efforts during the contract period, recapitalization decision support capabilities have already been expanded by extending the analysis of individual equipment to the analysis of an entire equipment fleet and fleet decision support will be improved by incorporating advanced methods such as Reliability Centered Maintenance analysis. Finally, life cycle support will be augmented by leveraging performance and reliability data and tools to provide operations and maintenance managers more knowledge and control of availability and maintenance issues and decisions.

5.2. Life Cycle Engineering & Economic Decision System Projects

The following projects conducted during this contract period under the LEEDS® program include:

Ongoing Projects:

- Alaskan E-Craft Project
- AHM/LEEDS® Integration

Completed Projects

- LEEDS® Intelligent Maintenance Support (IMS) (December 05)
- LEEDS® Porting Study (December 05)
- Fleet Recapitalization Decision Support (March 06)
- Multimodal Maintenance Application Demonstration (December 06)

The projects are fully described in the next section.

Life Cycle Engineering & Economic Decision Systems

PROJECTS

Life Cycle Engineering & Economic Decision System Projects

Ongoing Projects

1. Alaskan E-Craft Project

Project Goal

To aide ship deployment and operation activities, LEEDS® will provide provisional documentation capabilities and engineering decision support during construction and service life. LEEDS® will serve as a provisional documentation repository for design and as-built data. This effort may also involve implementation of LEEDS® through inntegration with a ship-board monitoring system in order to capture and review equipment/ship health.

E-Craft is a program being funded by ONR and the State of Alaska to build a unique classification of naval craft. The craft will be used primarily by the Matanuska-Susitna Borough (MSB) as a fast ferry at the Knik Arm at Anchorage. Secondarily, it is intended to be used by ONR as a variable-draft landing craft advanced technology demonstrator. Because of RIT's past experience with ONR, LEEDS® was chosen to provide the capability to capture design and construction artifacts in order to assist ship evaluation and service.

Project Results to date

- Attended the August 05 design review meeting in Seattle, WA, where a technical briefing of LEEDS® capabilities was delievered.
- Began process to establish a Proprietary Information Exchange Agreement (PIEA) with MSB in order to commence receiving ship data.

2. AHM/LEEDS® Integration

Project Goal

The integration of AHM and LEEDS® is designed to allow users to base decisions on performance, usage, and alert data being generated by a ground vehicle. Benefits of the integegration will include the ability to compare vehicle performance against previously collected data, the ability to quickly assess the operatioal readiness of the vehicle, and the ability to interrogate historical data at service life milestones.

For stakeholders, including program managers, engineers, and maintainers who require greater visibility of the operational status of their vehicles, the integration of AHM and LEEDS® will provide tools for assessing a vehicle's health from previous mission data. The tool will allow users to take advantage of historical data in addition to allowing functional analysis of vehiclar sub-systems. If problems are found, LEEDS® will provide the capability to analyze system data surrounding the problem in order to provide further insight into the cause of the malfuction or warning.

Project Results to date

- Developed evaluation approach and criteria for graphing/charting software for integration with .NET development environment.
- Implemented Phase I functional specification and screen layout design.
- Completed roll-up of information graphs within platform hierarchy.
- Demonstrated early software release at 2005 Defense Maintenance Symposium.

booth at the 2005 Defense Maintenance Symposium

Completed Projects

1. LEEDS® Intelligent Maintenance Support (IMS), Completed December 2005

Project Goal

Case-based reasoning (CBR) is a form of knowledge management that utilizes past experience in order to guide users to problem resolution. It is the expectation that integration of CBR software tools with LEEDS® would be able to leverage existing data to provide significant maintenance support functionality. It was the goal of this project to benchmark existing CBR software and evaluate integration within LEEDS®.

Case-based reasoning (CBR) is an approach to problem solving and learning that has been seen as a technology that could benefit LEEDS®. It is commonly used for applications such as maintenance/diagnostic aides and customer call-centers. Being that LEEDS® is primarily a recapitalization decision support tool to be used by owners and engineers, a variety of data is acquired and retained through equipment life in order for the decision process to work effectively. Much of this data is useful to equipment operators and maintainers in the fulfillment of their jobs. As a result, LEEDS® has been designed to also support use by maintainers. This project involved the investigation of CBR philosophies, identified and reviewed commercially available software tools, and examined the feasibility of integration within LEEDS®.

Project Results

- Outlined the CBR process, including a general procedure and proper application.
- Identified top three CBR software tools out of ten.
- Proposed integration plan for best-in-class CBR tool within LEEDS®, including initial knowledge base population strategy.

2. LEEDS® Porting Study, Completed December 2005

Project Goal

Maintainers, operators, engineers and managers commonly use smaller, hand-held devices when performing their jobs. The purpose of this study was to evaluate smaller devices and examine the feasibility of running LEEDS® on such devices.

This was done by examining changes to LEEDS® to make it easier to use in small devices, and by evaluating the feasibility of using speech recognition software, wearable computers, and head-mounted displays in conjuction with the LEEDS® graphical user interface. Such devices investigated included: tablet computers, handheld computers, smartphones, wearable computers, and head-mounted displays.

Technical users gain quick access to critical manuals and drawings that are integrated within LEEDS®

Project Results

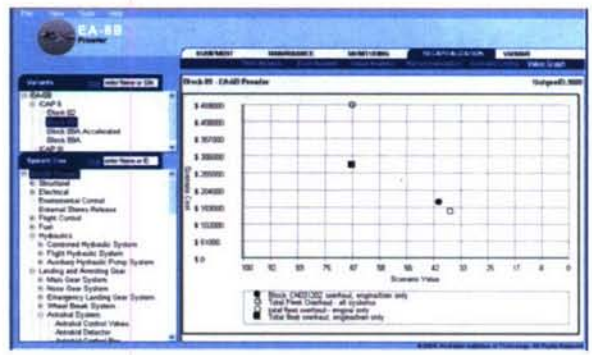
- Completed a comprehensive benchmark of small form-factor computers.
- Investigated software involved to support, including operating systems and voice-recognition technologies.
- Defined use-cases describing the hypothetical interaction of several hardware/software solutions.
- Recommended modifications to LEEDS® code-base to run more efficiently on thin-clients.

3. Fleet Recapitalization Decision Support, Completed March 2006

Project Goal

Program managers often face difficult decisions on howto allocate limited funds across their fleet for system upgrades. This project sought to extend the proven technical and economic decision support provided by LEEDS® to assess equipment recapitalization options, by developing enhanced tools to aggregate equipment data and to analyze the impact of investment options across the fleet.

In collaboration with the EA-6B program manager office and experts within the naval aviation field, platform variant and equipment data was collected and populated within LEEDS®, reflecting work breakdown structures (WBS) across the EA-6B fleet. User interface prototyping, requirements definition, and software development produced a fleet configuration management capability within LEEDS®. In addition, value analysis capability was developed to leverage the existing recapitalization assessment data with the newly developed configuration management functions. The resulting tool that was developed allows users to build, save and compare recapitalization scenarios across the fleet, in order to investigate the cost-benefit of each investment strategy.



Value analysis of recapitalization scenarios for the EA-6B Prowler

Project Results

- Developed fleet configuration management capability within the LEEDS® framework
- Populated LEEDS® database with variant and equipment WBS for the EA-6B platform.
- Developed and implemented scenario-based cost aggregation and value charting algorithms
- Completed testing/debugging and demonstrated early software release at 2005 Defense Maintenance Symposium.

4. Multimodal Demonstration, Completed December 2006

Project Goal

As a joint venture between the National Center for Remanufacturing and Resource Recovery (NC3R) and Vox Generation Ltd. (VoxGen), the goal of the Multimodal Demonstration project was to investigate and demonstrate the effectivemenss (improvement of quality, safety, accuracty and efficiency) of multi-modal interaction within maintenance and operational awareness tools, and to focus on a problem domain for a commercial application that could be correlated to one experienced by the U.S. military.

User interface multimodality, or the ability to input and receive data using more than one human-machine interface, allows direct access to information and the ability to collect/distribute knowledge from/between multiple stakeholders. Adoption of this technology within US industry and the military has been slow, attributable to several factors including common misconceptions surrounding voice-recognition performance. NC3R (as prime) and Vox Gen (as subcontractor) partnered to identify an application and demonstrate the capabilities of multimodal technology within the domain of US military operations and maintenance.

Over the course of seven months, an iterative, user-centered software development approach was employed to build and test multimodal applications to aide vehicle inspection, troubleshooting, and repair procedures. The project concluded with user trials of these applications under normal operating conditions and a successful live demonstration to representatives of Office of Naval Research, Office of Force Transformation, and Naval Sea Systems Command. It has been concluded by all stakeholders that this project has proven the functionality of multimodal technology with satisfactory performance and small-scale usability testing. It appears especially suited for vehicle inspection applications. Results from this project underscored the need for further operational piloting in order to develop a deployable multimodal system suited for military application.

Multimodal demonstration

Project Results

- Relative to vehicle limited technical inspections (LTIs), and preventative maintenance checks and service (PMCS):
    - As a result well structured procedures, the inspection process and its content transitions easily to a voice-enabled application.
    - User requirements analysis has identified the need for a voice-only interface or a multimodal user interface
- Relative to vehicle maintenance troubleshooting and repair:
    - The troubleshooting/repair procedure is relatively well-structured, but its content (typically provided by OEMs) is not. This content requires significant modification and enhancement to become usable for a voice-application.
    - User requirements call for the use of a multimodal user interface
    - A voice-enabled procedure would be considered a Class V+ IETM due to the content structure necessary for audible comprehension by a user.
- User trials have successfully demonstrated the utility of multimodal interfaces, but a pilot is necessary to modify and validate systems architecture before any application will be ready for fielding.
- Representatives from ONR, OFT, and NSSC that attended the final demonstration agreed there is a need for this capability within the US military. VoxGen and RIT agreed to jointly pursue additional sources of funding for application deployment.

Material Aging

6. Material Aging

6.1. Description of Material Aging

Material aging is the principal cause for the reduction of reliability and the decrease in the margin of safety for engineering systems as they progress through their product life cycle. In this process a system's components, over time, may change their appearance, dimensions, or physical and mechanical properties. NC3R's Material Aging program focuses on the development of several interacting technologies to address these issues, including laboratory inspection techniques using non-destructive inspection methodologies, aging and failure propagation models for crucial mechanisms such as fatigue, wear, and corrosion, and prediction of remaining life (prognostics) for essential system components. Table 6.1 illustrates the current efforts using these technology sets: reverse engineering using 3D laser scanner techniques, dimensional restoration of metallic surfaces, and aircraft hydraulic systems testing.

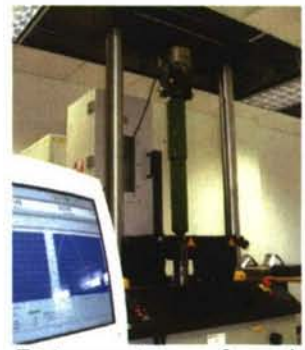
Table 6.1. Material Aging Activities

	Previous Development	Current Initiatives	Future Work
Reverse Engineering -3D Laser Scanner	• Develop and demonstrated a procedure for generating a solid model of an A-6E turtleback • Developed and demonstrated procedures for inspection of components. • Developed procedures for incorporating CCM data in the 3d laser scanner's point cloud	• Developing techniques to quickly and accurately bring point cloud data into solid modeling programs • Determining methods for increase the accuracy of the measurements • Developing techniques for using 3D Laser Scanning as an inspection technique	• Develop methodology for using 3D Laser Scanner for configuration control
Dimensional Restoration of Metallic Surfaces	• Purchase low cost, portable flame spray equipment • Developed techniques for thermal spraying plastic for remanufacturing of LAV drive shafts	• Started a program for developing for identifying thermal spray powders and techniques for dimensional restoration of cast iron	• Continue the development and develop machining techniques for the thermal spray coatings
Aviation Hydraulics	• Initiated test bed development on A-6E	• Completed Test Bed Development	• Initiate Hydraulic Testing

Technology Gaps and Research Objectives

The ongoing NC3R research program evaluates, develops, and applies material aging technologies to increase the useful life of either existing or new component or system designs and to develop cost-effective material salvage techniques for "worn" components.

NC3R has used the Physics of Failure Method to study the material aging process. In this process, a root cause failure analysis is performed first, using optical and scanning electron microscopy techniques, to determine the material aging mechanism on a macro or microstructural level. Then, using computer aided simulation the failure mechanism is replicated. Finally, the simulation is verified using laboratory tests and components or subassemblies designed to replicate the aging mechanism.


Fatigue testing performed on a LAV shock

Based on these methodoligies NC3R has developed several material aging capabilities during this contract period. They include:

- Structural health monitoring and condition assessment
- Material based prognostics
- Signature Analysis
- Restoration

Condition assessment understands which material aging mechanism is present and the extent to which the aging has affected function as well as the physical and mechanical properties of the component.

Material based prognostics are used to determine the remaining life of a component that has undergone material aging. These prognostics are obtained by initally simulating the material aging mechanism in the laboratory and then verifying it by running components or simulated components to failure.

The ability to predict the time to failure, on a real time basis, benefits Asset Health Management (AHM) systems and has the potential for reducing overall life cycle costs. NC3R is using these material based prognostics to generate predictive models from simulated laboratory testing and fault propagation. This prognostic development uses component or subassembly testing and is verified using subscale or full scale systems.

Signature analysis is concerned with the analysis of signals obtained from subassemblies or components. It is a diagnostic technique where certain parameters from a set of characteristic signals are extracted when operating a particular device. These parameters can provide useful information about the "state of health" of the device.

Material restoration brings a component that has been in service back to a pristine, like-new condition. A restoroation technique is selected after a root cause failure analysis has identified the material aging mechanism. By understanding how the component failed engineers are able to utilize the proper restoration technique to return the component to service. This process can also improve the performance of the component by providing increased resistance to the material aging mechanism. For example, if the material aging

mechanism identified is corrosion, a material restoration technique can be selected to have improved corrosion resistance over the original material.

Through the understanding of material aging and the utilization of the above capabilites, NC3R has accomplished the following:

- The insertion of design or material changes to increase the relibility and life of a component or system.
- The development of material restoration techniques to increase the useful life of components by restoring them to an "as new" condition.
- Accurate prediction of the remaining life of selected components or systems.

Table 6.2 shows the capabilities and enabling technologies developed to support the Material Aging Program during this contract period.

Capabilities	Enabling Technologies
Structural Health Monitoring (Condition Assessment)	Damage Detection (Nondestructive Inspection)
Material Aging Prognostics	Structural/Analytical Analysis
Restoration	Signature Analysis
	Root Cause Failure Analysis
	Fault Propagation (for Predictive Models)

Table 6.2. Material Aging Capabilities and Enabling Technologies

During the contract period, NC3R applied this expertise towards the dimensional restoration of metallic surfaces, the production of solid models from 3D laser point clouds, and the transformation of the center's A-6E Intruder research plane into a hydraulic test bed.

NC3R worked with the US Marine Corps to restore drive shafts used on the Light Armored Vehicle. Using a portable, propane fueled flame spray system; a 0.25 inch thick 316 or 420 stainless steel coating was applied to a cast iron surface. This coating had a good physical appearance and good adherence. The coating system is also less costly than typical thermal spray systems and is portable.

NC3R also demonstrated a procedure for generating solid models using a 3D laser scan system. These solid models will be used for reverse engineering components that do not have engineering drawings. During the contract period, NC3R reverse engineered an A-6E mid-turtleback. NC3R also developed and demonstrated a method of incorporating CMM data into the point cloud. This greatly increases the dimensional accuracy of the solid model and is very important when reverse engineering machined surfaces.

Finally NC3R has begun initiation of a hydraulic test bed for use with an A-6E Intruder stationed at their facility at RIT. The project will assist ONR in testing the robustness of

the system and recommend possible design and material changes. Currently, all hydraulic lines have traced and any broken or missing lines were replaced. In addition, any missing hydraulic cylinders were replaced. A method for controlling the actuation of the hydraulic cylinders was developed and a control diagram has been created.

6.2. Material Aging Projects

The Material Aging program funded by this contract is enhancing NC3R's technical capcity and supporting numerous DoD programs and platforms. During the contract period the program focused on understanding material aging and applying this knowledge to structural health monitoring, component restoration, and material based prognostics. The technologies developed include finite element analysis for structural modeling (EA-6B landing gear uplock), fatigue life prediction (EA-6B Hydraulic Actuator), applying signature analysis techniques (Signature Analysis and Prognostic Development for LAV Planetary), root cause failure analysis (Prognostic Development for LAV Planetary, EA-6B Hydraulic Actuator), and solid modeling (EA-6B Hydraulic Actuator and EA-6B Turtleback Remanufacturing).

Ongoing Projects:

- EA-6B Material Aging Phase II
  - Aviation Hydraulic Testing
- Remanufacturing Process Development
  - Thermal Spray Coating of Metal Power on Steel
- Reverse Engineering
  - 3D Laser Scanning Development

Completed Projects:

- EA-6B Material Aging
  - EA-6B Nose Gear Lock-up Evaluation (May 05)
  - EA-6B Flaperon Actuator Analysis (Sept. 04)
  - F404 Engine Valve Remanufacturing (Oct. 05)
  - EA-6B Turtleback Reverse Engineering (Nov. 05)
- Material Aging Light Armored Vehicle
  - Light Armored Vehicle: Planetary Drive Systems (May 05)
  - Prognostics for Light Armored Vehicle Planetaries New Bushing Material (March 05)
- Non-Destructive Test Methodology Development
  - Optical Imaging (Aug. 05)
- Remanufacturing Process Development
  - Pilot Application Optical Scanning Equipment Training and NDI Procedures Development (Sept. 05)

The projects are fully described in the next section.

Material Aging

PROJECTS

Material Aging

Ongoing Projects

1. EA-6B Material Aging Phase II Projects

Hydraulic System Pressure Variation

Project Goal

To determine the effect of extending wing flaps, slats, landing gear and tail hook on hydraulic line pressure and flow

NC3R is working with NAVAIR to determine the cause for hydraulic leaks that occur when the wing flaps and stabilizers, landing gear, and tail hook are extended. This is accomplished by using a retired A-6E aircraft at NC3R and actuating the remote systems with the plane on the ground.

Project Results to Date:

- Developed report that summarizes the effect of extending the flaps, stabilizer, landing gear, and tail hook on hydraulic pressure flow and temperature.
- Identified locations where any hydraulic leaks occurred.

2. Remanufacturing Process Development

NC3R is working with the PM-LAV Office and USMC Maintenance Facilities to identify subassemblies or components that are candidates for remanufacture. Once subassemblies or components are identified a process for remanufacturing these components or subassemblies will be developed and demonstrated.

Dimensional Restoration of Metallic Surfaces
Thermal Spray Coating of Metal Powder on Steel

Project Goal

Develop a low capital cost metal flame spray process for dimensional restoration of worn or corroded steel surfaces.

NC3R used a low cost thermal spray gun to apply various metal powders to cast iron and steel. Currently, cylinder heads or engine blocks are restored by welding on additional material and then machining the excess material back to the original print dimension. Since the welding applies a significant amount of material to a surface, approximately 0.40-0.60 inches, there is a significant amount of machining required to achieve the desired print dimension.

metal flame spray

One way to reduce the amount of machining required is to use a flame spraying method instead of welding for the dimensional restoration. In the flame-spraying process, oxygen and a fuel gas, such as acetylene, propane, or propylene, are fed into a torch and ignited to create a flame. Powder is injected into the flame where it is melted and sprayed onto the work piece

The primary restoration goal was to rebuild surfaces on large engine heads and blocks. A dense adherent steel coating would allow an engine rebuilder to apply a heavy, uniform steel coating to an engine head in significantly less time than it would take to weld a repair layer on the same surface. It would also cause less thermal distortion and heat damage to the base metal than welding.

Results

- Thinner metal coatings (0.025 inches or less) had very high adhesion while thicker coatings developed progressively lower adhesion strength.
- Studies to improve the adherence of the thicker thermal sprayed coating were unsuccessful.
- It was determined that this particular equipment was limited to low build repairs.

3. Reverse Engineering

3-D Laser Scanner Development

Project Goal

Develop a process for reverse engineering complex parts using 3D laser scanning techniques

A 3D laser scanner optically generates a line of points, repeatedly, until the coordinates of all the scans can be joined together to comprise the three dimensional topography of the scanned object. NC3R is developing techniques for using 3D laser technology of rapid reverse engineering of complex components.

Results

- Develop and demonstrated a procedure for generating a solid model of an A-6E turtleback
- Developed and demonstrated procedures for inspection of components.
- Developed procedures for incorporating CCM data into the 3D laser scanner's point cloud.

Digital data capture using a laser scanner

Completed Projects

1. EA-6B Material Aging Projects

EA-6B Nose Gear Lock-up Evaluation, Completed May 2005

Project Goal

Perform a Finite Element Analysis (FEA) on the EA-6B Uplock Support Bracket.

Several failures have occurred on the EA-6B Uplock Support Bracket and NAVAIR requested that a Finite Element Analysis be performed to determine design or material changes that could prevent these failures. The static finite element analysis evaluated the nose gear configuration and sequence of operation to determine worst case loading, load location, and direction using:

- Load values based on capacity of the Nose Gear Actuation Cylinder
- Properties for 2014-T4 Aluminum Alloy (yield = 40 ksi, E =10.6 x 106 psi)

Project Results:

The results of the finite analysis were:

- Cylinder Retraction resulted in highest stresses and most widespread areas of overstress
- Stress Distribution showed highest stresses in the bottom flange, door crank mechanism support, and vertical stiffeners
- Design criteria, in-service load data, and failed parts are needed to perform a more in-depth evaluation

EA-6B Flaperon Actuator Analysis, Completed September 2004

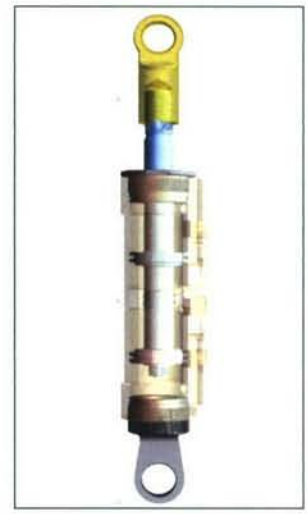
Project Goal

Determine the root cause for the fatigue failures of the flaperon actuator and determine a method for extending the life of this component.

Several fatigue failures of the EA-6B flaperon actuator have occurred. NC3R supported the EA-6B engineering team by modeling the flaperon actuator to determine the reason for the fatigue failures. The model was then verified by simulation testing. Using both the model and simulation results, recommendations were made to increase the life of the flaperon actuator.

Project Results:

- Delivered recommendations for a design change and a new cleaning process to increase the fatigue resistance of the flaperon actuator
- NADEP Jacksonville has adopted both recommendations



EA-6B flaperon actuator analysis

F404 Engine Valve Remanufacturing, Completed October 2005

Project Goal

The project goal was to first summarize the root cause failure analysis results and then present several remanufacturing options for the electrohydraulic servo valve.

The F404 Fan Variable Geometry (VG) actuator (Part Number 5033T53P03) is a high value component that is currently being scrapped when the valve can no longer be adjusted to its null value. The actuator is used on all FA-18A, B, C, and D aircraft operating the F404-400 and 402 engines. The actuator provides an output force and motion to a variable fan stator system. This system is used during both normal engine operation and when missiles are fired from certain wing positions to reduce the potential of an engine stall.

Rudder Actuator EA-6B

Project Results:

- Identified root cause for the actuator not fully stopping at the null.
- Developed a potential method for remanufacturing the servo valve
- Transferred technology to NAVDEP Jacksonville, Florida.

EA-6B Turtleback Reverse Engineering, Completed November 2005

Project Goal

Perform a cost benefit study to determine the best options for providing the Navy with additional EA-6B Turtlebacks

NC3R worked with NAVAIR to determine the best options for providing the Navy with additional EA-6B aft turtlebacks. Remanufacturing existing turtlebacks was eliminated because the condition of the existing EA-6B or A-6 turtlebacks required significant rework which would increase the remanufacturing costs significantly. The best option was to fabricate new turtlebacks using a modified design that was easier to manufacture and less susceptible to corrosion.

Results:

- Delivered two flight ready turtlebacks
- Supplied a production cost for additional fabrication

2. Material Aging Light Armored Vehicle

Planetary Drive Systems, Completed May 2005

Project Goal

Determine reason for planetary drive to run at elevated temperatures.

NC3R worked with the PM-LAV Office to quantify the root cause for planetary drive systems on LAVs to run at higher temperatures than other, similar planetary drives. The elevated operating temperatures cause these planetary drives to fail.

Project Results

- Identified the root cause for the elevated temperatures.
- Developed an option to reduce the operating temperatures of the system

Prognostics for Light Armored Vehicle Planetaries New Bushing Material, Completed March 2005

Project Goals

The project goal was to evaluate a new bushing material for the LAV planetary.

A root cause failure analysis performed at NC3R on a failed planetary showed that the reason for the planetary "lock-up" was the bushing had softened and was extruded from the planetary gear assembly. The extruded planetary bushing then flowed between the planetary gear and carrier plate preventing the planetary gear from rotating and "locking-up" the planetary drive. If the bushing can be replaced with a bushing with improved temperature tolerance and load bearing capability the operability of the LAV planetary drive will be improved.

Project Result

- A final report was issued summarizing the testing and recommendations by NC3R.

3. Non-Destructive Test Methodology Development

Optical Imaging, Completed August 2005

Project Goal

The objective of this study was to determine if optical imaging techniques can detect wear and corrosion on steel and aluminum components.

Modern high resolution digital cameras can facilitate the capture of an image encompassing a relatively large area and high speed computing systems can quickly process that image, yielding metrics that relate to the surface being examined. In addition, as imaging techniques are non-contact and require minimal setup, the eventual automation of inspection processes becomes more feasible. This will result in increased productivity and reduce reliance on highly trained operators. As NDI imaging techniques are "trained," estimations of the remaining life for a part will become more feasible.

NC3R undertook a study to evaluate the effectiveness of these technologies in detecting wear and corrosion on steal and aluminum surfaces. Preliminary data was then transferred to ONR for further study and analysis.

Project Results:

- NC3R tests illustrated a preliminary relationship between the surface roughness and optical reflection.

4. Remanufacturing Process Development

Remanufacture of LAV Drive Shafts Completed September 2006

Project Goal

Determine remanufacturing processes for LAV drive shafts currently being scrapped

The objective for the LAV drive shaft remanufacturing project was to develop an alternative process to recoat the outside surface of existing LAV drive shafts. Each drive shaft costs approximately $750. Presently, these shafts are being discarded once one of the following happens:

- The seal on the female and male mating surface becomes damaged.
- The nylon surface coating wears, allowing rust, dirt, water, etc. to negatively effect operation.

Successful development and implementation of an LAV drive shaft recoating process would result in a far more cost effective process; saving up to 700 dollars per shaft.

In addition to the LAV drive shaft recoating study, NC3R developed a seal replacement process. The existing seals used in the drive shafts are no longer manufactured. Therefore, NC3R worked with an outside company to manufacture appropriate seals for the component.

Results:

- Produced report detailing a remanufacturing process for an LAV driveshaft
- Transferred remanufacturing process to Albany and Barstow Depots
- Identified manufacturer for drive shaft seals

Applying coating to a drive shaft

MTRAC

Modernization Through Remanufacturing and Conversion

7. Modernization through Remanufacturing & Conversion (MTRAC)

7.1 Description of MTRAC

NC3R's Modernization through Remanufacturing and Conversion (MTRAC) program develops tools and processes to aid in design for remanufacturing, remanufacturing assessments, cost estimations for upgrade, and technology insertion into existing military programs.

Budget constraints, lengthy acquisition processes, and demanding operational requirements have forced the services to extend the service life of many combat systems far beyond original expectations. Maintenance of these systems becomes increasingly costly as they age because of technological advances and the associated obsolescence/availability and scarcity of support from original equipment manufacturers (OEM). Therefore, MTRAC efforts have focused on developing processes, software, tool kits, and technology assessments that allow for rapid reverse engineering and prototyping as well as the building and testing of electrical components with the same functional capabilities as the original design

During the contract period, the MTRAC program utilized these capabilities through partnerships with a number of DoD military depots, including Albany, Georgia (USMC) and Jacksonville, Florida (Naval Air Depot). NC3R evaluated new technologies that could be implemented by the depots to recover parts that were previously discarded.

Instructing restoration process

In addition, support was provided to the Marine Corps Systems Command's Capability Assessment Support Center (CASC) to improve the visibility of life cycle issues for their ground equipment. These efforts targeted CASC's platform upgrades to improve the Reliability, Availability and Maintainability (RAM) metrics of fleet equipment. NC3R has provided the technology to enable RAM assessments in a more proactive manner, allowing issues to be analyzed and corrected in a timely fashion.

Finally, to reverse the growing trend in product obsolescence, MTRAC has developed an Innovation Based Design (IBD) process that enables maximization of useful product life through application of sustainable design principles. IBD facilitates planned, incremental technology integration and enables a product to maintain a competitive level of performance and reliability over its lifetime, at a cost and risk substantially less than replacing the existing system with an entirely new one.

A listing of current MTRC efforts is provided in Table 7.1.

Table 7.1. Modernization through Remanufacturing and Conversion

	Previous Development	Current Efforts	Future Work
LAV Drive Shaft Remanufacturing	• Developed Remanufacturing Process • Transferred Process to Albany, Ga. and Barstow Ca. Maintenance Centers	• Continue to Support Process	
LAV-JV 3179	• High-level engineering/manufacturing technology assessment • Defined Functions and standards of performance. • Captured Detail Electronic Design in Software. • Component Identification, obsolescence analysis, and Bill of Materials. • Design and build prototype.	• Develop board testing and verification procedures • Develop Technical Data Package. • Find an industrial partner and deliver 100 circuit card assemblies for operational use.	• Maintain/upgrade BOM and TDP for technology upgrades and obsolescence issues for additional board runs.
Rapid Reverse Engineering and Manufacturing of Electronics	• Develop the requirements for reverse engineering and prototyping of aging electrical boards. • Acquire one operational board facing obsolescence and use it to develop the general process for reverse engineering of aging electronics.	• Develop the specific process, procedures and tools required for evaluating and reverse-engineering of aging electronic circuits. • Acquire more aging electronic boards to further refine processes developed. • Look for programs and systems outside of PMLAV that would benefit from this process.	• Develop a viable reverse-engineering process and toolkit that allows technology upgrade, obsolescence protection and rapid manufacturing of new board runs for aging electronics.
Sustainment Test-bed for Ground Combat Vehicles	• Develop process designed to resolve the problems associated with DOD long design to acquisition lead time and continued platform life extension.	• Working three demonstration projects with specific platform to verify developed processes.	• Develop Sustainment Test bed. • Target new platforms for application of MTRAC techniques.

Research Objectives

Sub-Task: Support Marine Corps Depots

The goal of this effort was to provide the Marine Corps Depots at Barstow CA and Albany GA with tools that can be applied to the remanufacture of tanks, trucks, and a variety of other vehicles, platforms, and equipment. Specific processes and equipment were targeted for research in order to incorporate technological advances into the remanufacture of combat vehicles and reduce their total system. In addition, initial efforts were made to establish a sustainment test-bed for the Program Management Office for Light Armored Vehicle (PM-LAV) in order to develop techniques and processes that reduced the risk associated with Diminishing Manufacturing Sources and Material Shortage (DMSMS). During the contract period, three demonstration parts were selected

to demonstrate and verify that MTRAC can provide a method for the opening of new product and procurement sources that meet or exceed new standards. The process developed will ensure continued support of DOD legacy systems for these parts thereby maintaining readiness while avoiding costly redesign. Future efforts will include establishing a DOD sustainment test-bed that will focus on providing new and innovative processes for providing continuing and alternative sources of parts for maintaining and modernizing aging ground combat platforms.

Sub-Task: Support Naval Air Depots/Naval Air Systems Command (NAVAIR)

The United States Navy faces an increasing need to extend the in-use system life of a number of their aircraft, as long design to acquisition lead times for new platforms have pushed back the time for their replacement. During this period, NC3R developed a number of strategies for extending the life of aircraft by leveraging a number of support technologies and methodologies such as reverse engineering, design capture, targeted end- of life data collection and remaining life testing.

fleet support research in one of NC3R's bays

These methods were applied in direct support to a number of fleet customers including the EA-6B, and F-18 Naval Aviation Program Managers. For these projects, reverse engineering techniques were used to generate original equipment design specifications and tolerances when this information was unavailable at the remanufacturing stage. Design capture was also used to collect information from equipment at end-of-life, enhancing improvements to the design process, while life-cycle costing methodologies were developed to support intelligent design selection by uncovering cost information up to and including system end-of-life. In each case the aim of NC3R's research during this contract period was to apply the elements of MTRAC towards target customers with aging equipment to provide real value in terms of increased capability, longer life, less maintenance, and decreased costs. Future efforts will focus on developing technologies to effectively resolve support problems for aging aircraft and specifically target hydraulic systems on the E-A6B Prowler.

Sub-Task: Reliability, Availability, and Maintainability (RAM)

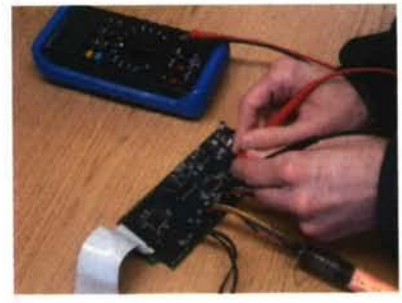
During this contract period NC3R entered discussions with the DoD Office of Force Transformation and PM-LAV to identify projects that leverage existing RAM tools developed in conjunction with Marine Corps Systems Command that provide better metrics for fleet analysis. The effort will seek to utilize existing databases such as the Marine Corps Equipment Readiness Information Tool (MERIT), along with processes developed at NC3R, to provide Program Managers with tools for configuration management, fleet trending, and economic analysis which can aid them in the

remanufacturing decision process. Questions that these projects would answer for Program Managers include:

- I am currently at 75% Operational readiness…What are my top degraders that are affecting this readiness across the fleet? Across a variant? Across a unit?
- How long will it take to achieve a particular level of operational readiness given the current state of the logistics chain?
- If I purchase a work package that consists of the following items what will the impact be on my readiness?
- What is the current configuration of my fleet?
- How much will it cost me to upgrade across the fleet to a particular level of capability?

The work in this area has been focused on extending the capability of the NC3R Life-Cycle Engineering and Economic Decision System (LEEDS®) to answer the above questions. Future efforts will develop projects in direct support of readiness decision making and enhancement of remanufacturing opportunities for platforms returning from combat operations in support of the Global War on Terrorism.

Sub-Task: Develop and Document Processes for the Rapid Reverse Engineering of Aging Electronics.



board testing

NC3R developed a process for the rapid reverse engineering of electronic components and boards to support DoD customers faced with diminished manufacturing sources, material shortages, and the lack of access to technical data packages needed for the development of alternative sources of supply. These processes included trade studies and technology assessment tools to provide the Program Manager a reasoned approach to decide how best to support this equipment with the optimal balance of risk, cost, and capability to extend its remaining life. NC3R also developed a methodology to rapidly identify board functions, key requirements, and potential obsolescence issues. These techniques were then verified during this contract period through successful direct support applications, the reverse engineering of a communications board for PM-LAV. Future efforts will focus on finding other DoD platforms facing similar sustainability and technology obsolescence challenges to further hone NC3R capabilities.

Sub-Task: Unmanned Sea Surface Vehicle (USSV) Life Cycle Design and Cost Implications Study

The objective of this project was to structure a life cycle design process that illustrates cost implications of design changes for the USSV. The life cycle design process developed during this project is a systematic analysis which increases useful product life, capitalizes on emerging technologies, and minimizes environmental impact through cost-effective, incremental technology integration. This process is typically used in new product design or continuous product improvement. This structured life cycle design process:

1. Determines the value relationships between major functions in the design to present opportunities for cost reduction as well as methods to improve the value of a function,
2. Develops technology recommendations and roadmaps to determine when these technologies will be implemented into the design,
3. Performs sensitivity analyses to determine how design changes or technologies affect performance and life cycle costs.

7.2 MTRAC Projects

The primary projects that were conducted under the MTRAC program include:

Ongoing Projects:

- Sustainment Test Bed 339 Support

Completed Projects:

- Light Armored Vehicle: Turret Auxiliary Power System (Nov. 05)
- Unmanned Sea Surface Vehicle (USSV) Life Cycle Design and Cost Implications Study (Dec. 05)
- Light Armored Vehicle: Intercom Circuit Board Reverse Engineering (Dec. 05)

The projects are fully described in the next section.

Modernization Through Remanufacturing and Conversion

PROJECTS

Modernization through Remanufacturing & Conversion

Ongoing Projects

1. Light Armored Vehicle: Sustainment Test Bed 339 Support, Began February 2005

Sub-task: 4.1 Support Marine Corps Depots

Project Goal

Developing technology solutions and testing/verifying alternative sources of commercial supplies for sustainment support of Marine Corps Ground Combat Light Armored Vehicles.

The Marine Corps Light Armored Vehicle has been extended past the originally planned operational life and as such PM-LAV has experienced increasing difficulty in obtaining the replacement parts that are needed to maintain its capability. LAV stakeholders submit to PM-LAV Defense Logistic Agency Form 339s for reporting engineering and technical issues that inhibit the acquisition of correct supply items. NC3R will periodically provide technical engineering expertise to PM-LAV in order to present solutions for procuring material in a timely manner for direct support of service warfighters.

Project Results to date:

- Investigation of Commercial-off-the-Shelf replacement for Light Armored Vehicle main hydraulic pump.
- Investigation of Commercial-off-the-Shelf replacement for Light Armored Vehicle Hydraulic Winch Motor for the LAV-R variant.
- Investigation of Commercial-off-the-Shelf replacement for Light Armored Vehicle Hydraulic Solenoid Valve for the LAV-AT variant.
- Form, fit, and function investigation for the Electronic Filter for the JV-2805 Communications System for the LAV-C2 variant.

Marine Corps Logistics Base in Albany, GA

Completed Projects

1. Light Armored Vehicle: Turret Auxiliary Power System, August 2004 through November 2005

Sub-task: 4.1 Support Marine Corps Depots

Project Goal

NC3R worked with PM-LAV to design, build, and test a Turret Auxiliary Power System (TAPS) prototype, providing a second source of power for the key electronic components of the LAV.

NC3R worked with PM-LAV to design a TAPS prototype that would prevent excessive voltage droop during incidents of short duration, high current loads that turn off many critical components within the LAV turret. In addition to preserving operational capability, as designed, TAPS provided for longer periods of "silent watch" a key to the vehicle's reconnaissance mission.

Project Results

- Developed Technical Data Package and Bill of Materials for a TAPS prototype.
- Built two TAPS prototypes one for testing and one for delivery to PMLAV.
- Designed and successfully completed a series of stationary and moving on-board vehicle tests of the prototype.

Turret auxiliary power system

2. Unmanned Sea Surface Vehicle (USSV) Life Cycle Design and Cost Implications Study, August 2004 through December 2005

Sub-task: 4.3 Reliability, Availability, and Maintainability

Project Goal

The objective of this project was to structure a life cycle design process that shows cost implications of design changes for the USSV.

The life cycle design process is a systematic analysis which increases useful product life, capitalizes on emerging technologies, and minimizes environmental impact through cost-effective, incremental technology integration. This process is typically used in new product design or continuous product improvement. This structured life cycle design process:

1. Determines the value relationships between the major functions in the design to present opportunities for cost reduction or methods to improve the value of a function,

2. Develops technologies recommendations and roadmaps to determine when these technologies will be implemented into the design,
3. Performs sensitivity analyses to determine how design changes or technologies affect performance and life cycle costs.

Project Results:

- The results of the value engineering study showed that the following functions for both the HS and LS USSV design were poor values: Hull design, Obstacle avoidance, receive data, transmit data and generate electricity. The stabilize craft and recover craft functions for the HS USSV were also poor values.
- The technology road mapping study identified the following technologies that should be monitored and applied to the USSV design within the next 7-10 years: rotary diesel engine, an electric drive, M-Body Hull technology, lighter weight, more durable hull materials, and advanced alternator designs containing high strength permanent magnets and superconducting windings.
- The sensitivity analyses showed that because the HS and LS USSV crafts have limited redundancy, single point failures can cause substantial or complete loss of platform capability. In addition, predictive maintenance, on-board monitoring, and scheduled replacement of age related components will increase the reliability and availability of the craft. Also, the analysis showed that because of an assumed seven-year design cycle for the craft, any increase in usage, duty cycle, or platform life, will result in a significant per mission cost increase.

3. Light Armored Vehicle: Intercom Circuit Board Reverse Engineering, February 2005 through December 2005

Sub-task: 4.4 Rapid Reverse Engineerng of Aging Electronics

Project Goal

Reverse engineer critical circuit boards for the intercom of the LAV Command and Control variant and provide first engineering samples and detailed design data

Critical circuit board components of the LAV-C2 intercom control box cannot be procured by PM-LAV because a complete design package is not available and the technical rights owner quoted a price at over $30,000 dollars per board. NC3R reverse-engineered these circuit boards, prototyped and tested first samples, and provided design details to support the purchase of critical repair parts.

Project Results:

- Reverse engineered and delivered a detailed technical data package for 3 circuit board assemblies of the LAV-C2 intercom.
- Built and delivered five prototype circuit card assemblies, designed board/operational level

old and new circuit boards

testing procedures, and provided test results of circuit boards.

- Provided life extension options, with three sources of supply, through next communication revision that would result in a $3.3 million savings for PM-LAV with a planned 100 board buy.
- PMLAV used the NC3R deliverables to leverage the original equipment manufacturer to provide the needed equipment.